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PILOT FIELD DEMONSTRATION OF ALTERNATIVE FUELS IN FORCE PROJECTION PETROLEUM AND WATER DISTRIBUTION EQUIPMENT

INTERIM REPORT
TFLRF No. 449

by
Adam C. Brandt
Edwin A. Frame
Robert R. Warden
Peter J. Wostarek

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Mr. Eric Sattler
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD21)

September 2014

Disclaimers

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UNCLASSIFIED: Distribution Statement A. Approved for public release

September 2014

Approved by:

Gary Bessee

Gary B. Bessee, Director
U.S. Army TARDEC Fuels and Lubricants
Research Facility (SwRI®)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
09/04/2014

2. REPORT TYPE
Interim Report

3. DATES COVERED *(From - To)*
September 2012 – September 2014

4. TITLE AND SUBTITLE
Pilot Field Demonstration of Alternative Fuels in Force Projection Petroleum and Water Distribution Equipment

5a. CONTRACT NUMBER
W56HZV-09-C-0100

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brandt, Adam C.; Frame, Edwin A.; Warden, Robert R; Wostarek, Peter J.

5d. PROJECT NUMBER
SwRI 08.14734.21.(301-304)

5e. TASK NUMBER
WD 21

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®)
Southwest Research Institute®
P.O. Drawer 28510
San Antonio, TX 78228-0510

8. PERFORMING ORGANIZATION REPORT NUMBER
TFLRF No. 449

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army RDECOM
U.S. Army TARDEC
Force Projection Technologies
Warren, MI 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
UNCLASSIFIED: Dist A
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
To evaluate the potential impact of Army wide use of a volumetric 50/50 blend of JP-8 and Fischer Tropsch derived synthetic paraffinic kerosene (FT-SPK), three petroleum and water distribution systems were identified for compatibility testing by the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC). They included two Force Projection Technology (FPT) diesel driven pumping assemblies of 350 and 600 gallons per minute (GPM), and the Advanced Aviation Forward Area Refueling System (AAFARS). The 350 and 600 GPM units were tested by recirculating water in a 20,000 gallon collapsible tank, while the AAFARS system was evaluated recirculating the FT-SPK/JP-8 fuel blend throughout the entire AAFARS modular fuel distribution system. Both were evaluated in a 400 hr test cycle at rated conditions, and both were operated successfully on the FT-SPK/JP-8 fuel blend, without experiencing any engine related performance issues or material compatibility problems.

15. SUBJECT TERMS
Fischer Tropsch, synthetic fuel, alternative fuel, FT-SPK, synthetic paraffinic kerosene, Force Projection Technology, Advanced Forward Area Refueling System

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	43	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

To evaluate the potential impact of Army wide use of a volumetric 50/50 blend of JP-8 and Fischer Tropsch derived synthetic paraffinic kerosene (FT-SPK), three petroleum and water distribution systems were identified for compatibility testing by the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC). They included two Force Projection Technology (FPT) diesel driven pumping assemblies of 350 and 600 gallons per minute (GPM), and the Advanced Aviation Forward Area Refueling System (AAFARS). Both consist of a small compression ignition engine driven pumping assembly which was operated for 400 hours under rated load conditions to assess the performance and compatibility of the systems with the use of alternative fuels. The 350 and 600 GPM units were tested by recirculating water in a 20,000 gallon collapsible tank, while the AAFARS system was evaluated recirculating the FT-SPK/JP-8 fuel blend throughout the entire AAFARS modular fuel distribution system.

Both systems were successfully operated using the FT-SPK/JP-8 fuel blend over their respective 400 hr tests. Each system yielded satisfactory performance when operated on the FT-SPK/JP-8 test fuel, and each system was able to be operated to their full capacity as dictated by the test facility and hardware it was evaluated with. No fuel related engine performance, or material compatibility issues were noted with hardware components that came into contact with the test fuel itself (i.e., fuel engine supply and return lines, AAFARS suction/discharge lines and fittings). Minor leaks were experienced from various fittings during the AAFARS testing portion, but were ultimately attributed to mechanically damaged o-rings and fittings prior to testing, not as a result of material compatibility of the FT-SPK/JP-8 fuel blend.

It is expected that these two systems, assuming proper starting function, can be operated on FT-SPK blends by the Army in the future without experiencing any major compatibility problems or performance shortcomings.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period of September 2012 through August 2014 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT-FLT) served as the TARDEC contracting officer's technical representative, and the project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical and administrative support staff.

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ACRONYMS AND ABBREVIATIONS

AAFARS – Advanced Aviation Forward Area Refueling System

BTU – British Thermal Unit

°C – Degrees Celsius

cSt - Centistoke

°F – Degrees Fahrenheit

FIA – Fluorescent Indicator Absorption

FPT – Force Projection Technology

FT – Fischer Tropsch

FT-SPK – Fischer Tropsch Synthetic Paraffinic Kerosene

g - Gram

GPM – Gallon Per Minute

hr - Hours

JP-8 – Jet Propellant 8

lb - Pound

mL – Milliliters

mm - Millimeters

NEMA – National Electrical Manufacturers Association

psi – Pounds per Square Inch

psiA – Pounds per Square Inch Absolute

rpm – Revolutions per Minute

SAE – Society of Automotive Engineers

SwRI – Southwest Research Institute

TARDEC – Tank Automotive Research Development and Engineering Center

TFLRF – TARDEC Fuels and Lubricants Research Facility

vol% - Volume Percent

wt% - Weight Percent

µm - Micrometers

1.0 BACKGROUND AND INTRODUCTION

The future use of alternative fuels by the U.S. Army requires extensive compatibility and impact checks across a wide range of equipment. One critical area of that is the petroleum product and water distribution equipment. Without a knowledge of how these components will perform on alternative fuels, issues could arise in the transport and distribution of fuel for military operations, and the security of water supply used on the battle field.

To evaluate the potential impact of Army wide use of a volumetric 50/50 blend of JP-8 and Fischer Tropsch derived synthetic paraffinic kerosene (FT-SPK), three unique petroleum and water distribution systems were identified for compatibility testing by the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC). These systems were specifically chosen due to their fueling and cooling systems that are unique compared to other military ground equipment systems that have been tested during past research programs. The first two systems identified were Force Projection Technology (FPT) diesel-driven pumping assemblies of 350 and 600 gallons per minute (GPM) capacity. These systems consisted of two different capacity centrifugal pump assemblies direct driven by a small displacement compression ignition engine. These systems were operated on the FT-SPK/JP-8 fuel blend, and utilized water as the working fluid to load the pumping assembly. The third system identified was the Advanced Aviation Forward Area Refueling System (AAFARS). Similar to the FPT systems, it consisted of a small compression ignition engine driven pumping assembly, with the entire system being made of numerous hoses, fittings, distribution nozzles, and storage drums which make up the “modular” petroleum distribution system. During its testing, not only was the engine itself operated on the FT-SPK/JP-8 blend, but the blended fuel was also used as the working fluid to load the pumping assembly, being pumped through all the various modular components to assess material compatibility with the blended fuel. Each of these systems were operated for 400 hours at elevated temperature conditions to challenge the fuel injection system and distribution equipment that came in contact with the blended fuel.

All testing was completed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, TX. All tested hardware was provided by the U.S. Army TARDEC Force Projection Technology Team (FPT).

2.0 SYNTHETIC FUEL BLEND

The fuel blend tested in the FPT and AAFARS systems was a 50/50 volumetric blend of FT-SPK and a commercially sourced JP-8. The fuel blend contained 22.5 mg/L of DCI-4A CI/LI. Table 1 below shows select chemical and physical analysis results of the fuel that was used to evaluate each system. Specific notation was included for key properties for JP-8 in general, as well as the key resulting properties of the finished blend of FT-SPK/JP-8 as per MIL-DTL-83133H. As seen in the table, the finished fuel did meet the minimum requirements for aromatic content, distillation range, and derived cetane number as called out by the specification. The tested fuel is a good representation of what could be expected from a 50/50 fuel blend of FT-SPK/JP-8 in real world operation.

Table 1. AF7117 Test Fuel Chemical & Physical Analysis

Property	Test Method	TEST FUEL AF-7117	FT-SPK Blend Specific (MIL-DTL-83133H) Specifications	JP8 (MIL-DTL-83133H) Specifications
Density, 15C (g/mL)	D4052	0.7741		0.775, min
Kinematic Viscosity, 40C (cSt)	D445	1.23		
Sulfur *(wt%)*	D2622	0.0044		
Hydrocarbons by FIA	D1319			
Aromatic *(vol%)*		9.3	8, min	25, max
Olefin *(vol%)*		1		
Saturates *(vol%)*		89.7		
Heat of Combustion	D240			
GROSS *(BTU/lb)*		20,005		
NET *(BTU/lb)*		18,695		18,400, min
Flash Point *(°F)*	D93	119.3		
(°C)		48.5		38, min
SLBOCLE (g)	D6078	1900		
BOCLE (mm)	D5001	0.55		
HFRR (µm)	D6079	684		
Distillation *(°C)*	D86			
IBP		161.4		
10		169.9		205, max
20		172.8		
50		184.9		
90		219.1		
FBP		239		300, max
T90-T10		49.2	40, min	
T50-T10		15.0	15, min	
Cetane Number	D613	48.8		
Calculated Cetane	D976	46.6		
IQT	D6890	48.8	40, min	

3.0 FORCE PROJECTION TECHNOLOGY PUMP-ENGINE TESTING

The first systems tested were the FPT pump-engine assemblies. This section covers the FPT testing, and includes an overview of the test facility and equipment constructed and utilized to operate both of the systems, as well as individual discussions of results for each unit.

3.1 TEST FACILITY

A dedicated test area was prepared at TFRLF for the evaluation of the FPT pump-engine assemblies. Due to the large volume of fluid being moved by both pumps, the testing area selected was located at the rear side of an onsite covered storage building that contained a partially enclosed concrete slab, and was positioned next to a natural drainage area for the surrounding terrain. This allowed for location of the pump-engine module to be protected from any extreme weather conditions, while the adjacent drainage area would be capable of handling excess water in the unlikely event of a major leak, as both systems tested utilized a partially filled 20,000 gallon bladder of water as the primary recirculation reservoir. Additional details of each subsystem is discussed below.

3.1.1 Recirculation Loop

Both the 600 GPM and 350 GPM pump assemblies utilized the same recirculation loop to apply loading to the pump-engine assembly for testing. This loop consisted of a partially filled 20,000 gallon collapsible tank (i.e., bladder) of water, and 4″ supply and return hoses that interfaced between the tank to the pump-engine assembly. A basic line diagram of the recirculation loop is shown in Figure 1.

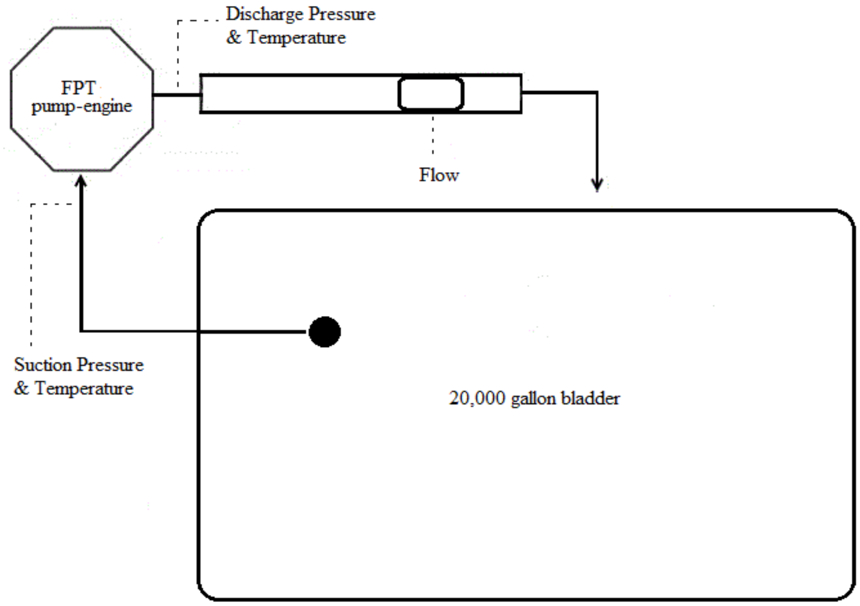


Figure 1. FPT pump-engine recirculation loop

Due to an uneven grade, the bladder was surrounded with large concrete blocks to prevent any potential movement of the tank that could result in damage to it or the nearby driveway. Figure 2 shows a photo of the 20,000 gallon tank and the makeshift retaining wall. Note the supply and return lines attached at the opposite ends of the tank (supply shown right, return shown far left).

Figure 2. 20,000 gallon collapsible recirculation tank (bladder)

Pressure safety switches were installed at various locations on the discharge side of the recirculation loop to provide the ability to safely shutdown pump-engines in the event of a major leak. An example of this can be seen downstream of the high-volume flow meter piping shown below in Figure 3 (safety switch circled in red).

Figure 3. FPT pump-engine discharge flow meter and pressure safety switch

3.1.2 Pump-Engine Location (Environmental Conditions)

Desired intake air temperature for testing was between 100 to 120 °F, to replicate conditions expected in desert type operation. To accomplish this, waste engine heat from the exhaust and engine cooling discharge was retained in the immediate testing area by enclosing the openings of the covered structure immediately surrounding the test rig. One side of the enclosure was formed by the main storage building wall which provided an impervious barrier to airflow. The opposite wall consisted of pre-existing sheet metal panels with approximately two foot air gaps at the top and bottom forming a natural breeze way. During testing the top gap was covered using heavy canvas tarps to prevent air flow, but the bottom gap was left open to allow for the passage of the 4″ supply and discharge water hoses at the pump-engine. The remaining two sides of the test area consisted of canvas covered gates at one end that enabled the large equipment to be moved in and out of the testing area, while the other utilized the same heavy canvas tarps as curtains to retain the heat while still allowing for technician passage during testing. The data acquisition console was positioned outside of the immediate testing area. This arrangement can be seen in Figure 4.

Figure 4. FPT testing enclosure

The exhaust of each engine was connected to flexible exhaust tubing and routed safely outside of the enclosed test area. This allowed for heat to be emitted into the immediate testing area by the pump-engine's exhaust manifold and piping, while preventing the build-up of toxic gases within the test area. The exhaust discharge for the test area can be seen below in Figure 5.

Figure 5. FPT exhaust discharge from enclosed testing area

3.1.3 Instrumentation

A mobile data acquisition and control system was utilized to operate the FPT pump-engine evaluation. This allowed for real-time monitoring and data collection over the entire 400 hr test, and added the capability of installing additional mechanical safeties to protect the test hardware, recirculation loop, and personnel. Data acquisition and control was provided by PRISM, an SwRI in-house developed software suite used throughout TFLRF for test cell data acquisition and control purposes. The mobile cart used can be seen Figure 6. It consists of the PRISM operator interface (i.e., main computer), the machine interface computer (additional DAQ computer), and all necessary data acquisition hardware (modules, power supplies, back planes, etc). All components were mounted inside a weatherproof mobile NEMA-4 enclosure for all weather outdoor operation.

Figure 6. Data Acquisition and Control System

3.2 600 GPM Pump Assembly

The following section includes discussion and results related to the testing of the 600 GPM pump-engine assembly.

3.2.1 Installation and Set Up

The 600 GPM pump-engine was tested first ensuring that the recirculation loop was capable of the highest nominal flow rate, as the smaller 350 GPM pump-engine was expected to use the same basic test arrangement. (It is worth noting that the actual 600 GPM rating of the first pump-engine tested was not able to be achieved due to suction side restrictions inherent of the bladder and supply line sizes. Despite that, the 600 GPM label is still used in reporting to differentiate between the two FPT pump-engines tested.) The 600 GPM pump-engine was placed into the testing area and connected to the recirculation loop using the previously mentioned 4″ supply and discharge hoses. Instrumentation installed for testing included engine speed, pump inlet pressure, pump discharge pressure, water flow rate, and a variety of temperatures to monitor the entire system. Select locations for key instrumentation is shown in Figure 7.

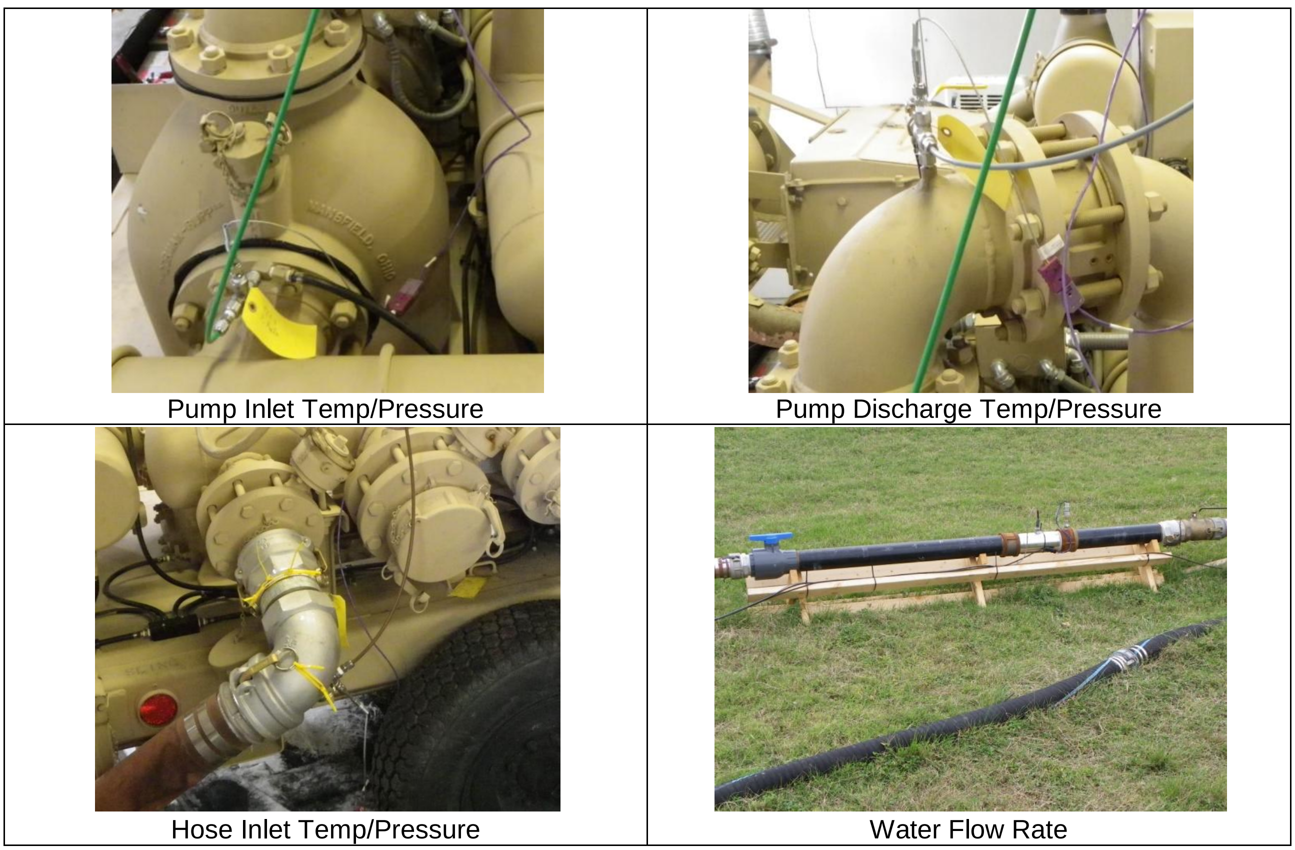


Figure 7. 600 GPM Instrumentation Locations

Prior to testing, fuel and oil filters on the 600 GPM pump unit were replaced, and the engine was charged using MIL-PRF-2104H SAE 15W-40 oil. Once complete, the pump and lines were primed with water, and the 600 GPM pump engine test setup was operated to conduct a brief shake-down to assess the flow loop performance, and identify any problems prior to testing. Apart from the previously mentioned suction side flow restriction limiting overall flow rate, no operational issues were noted, and testing was initiated.

3.2.2 **600 GPM Test Results**

Over the course of the 400 hr test, the pump-engine was shut down once daily to check the oil level and make any additions as necessary to maintain a safe oil sump level. Aside from this brief shutdown and daily checks, the test successfully ran the total 400 hr test duration continuously. A summary of the operational data recorded during testing is provided in Table 2.

Table 2. 600 GPM Operational Summary

Parameter	Average	Minimum	Maximum	Standard Deviation	Median Value
Engine RPM	2302	2211	2545	7	2302
Water Flow, GPM	201	121	330	23	192
Pump Outlet Pressure, psi	138.5	122.0	144.4	0.9	138.5
Hose Inlet Pressure, psi	8.1	3.9	19.3	1.8	7.5
Pump Inlet Pressure, psiA	12.7	8.3	13.7	0.8	12.9
Fuel Temperature, ° F	102.2	95.7	115.2	3.3	101.6
Intake Air, °F	99.9	68.8	121.9	8.1	100.4
Water at Pump Inlet, °F	126.5	75.3	136.8	10.7	129.6
Water at Pump Discharge, °F	127.2	75.7	138.1	10.7	130.2
Water at Hose Inlet, °F	127.7	76.0	138.4	10.7	130.8
Engine Oil Sump, °F	214.4	202.2	230.5	4.9	213.4
Air Outside Test Area, °F	65.1	46.5	87.9	10.0	64.8

The speed of the pump-engine during testing is shown in Figure 8. This speed was controlled by the pump rig manual throttle lever, which was kept at the full open position throughout testing. Momentary spikes in the plot were a result of startup and shutdown, when changing back pressure changed the loading on the pump outlet.

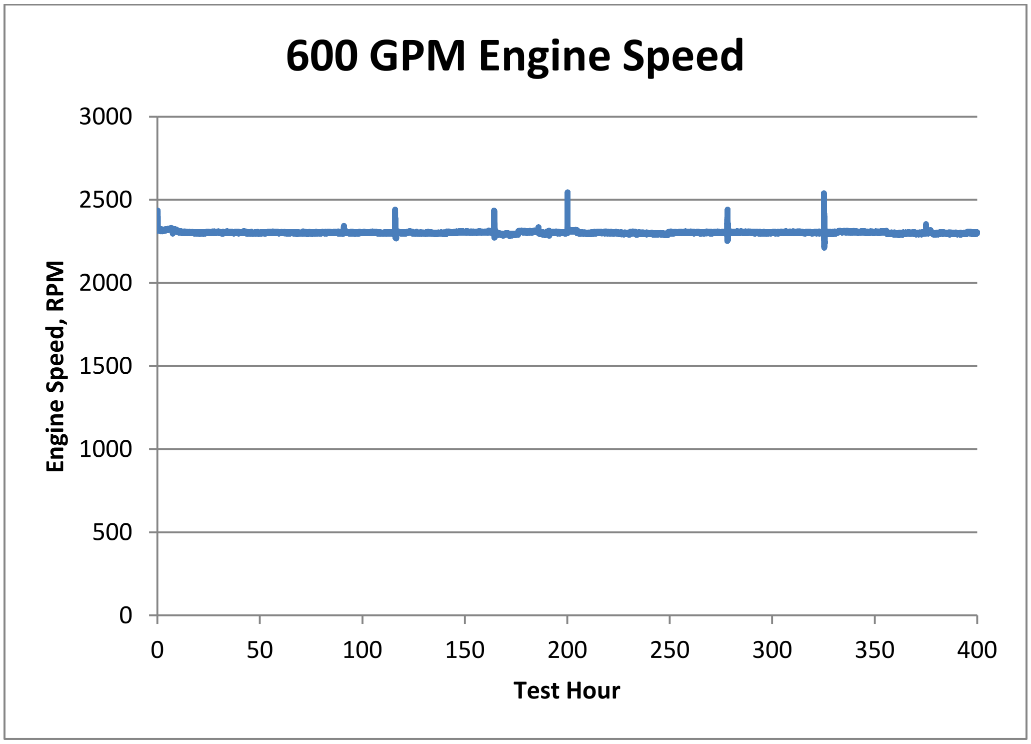


Figure 8. 600 GPM Engine Speed

In addition to the elevated air temperature, the fuel inlet temperature was desired to be maintained above 100 °F minimum, again to replicate desert type operation. The fuel inlet temperature profile over the course of the 400 hr test is shown in Figure 9.

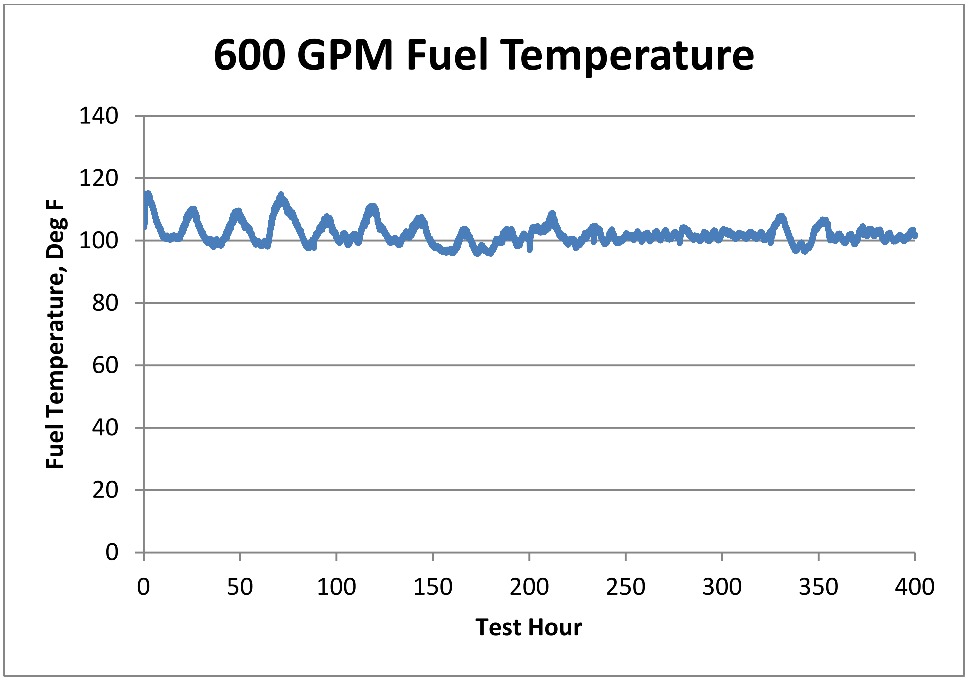


Figure 9. 600 GPM Fuel Temperature

As seen in the plot, there were a few instances of the fuel temperature dropping below the desired level. This was due to night time ambient temperatures cooling rapidly as a result of low humidity levels. Since overall fuel temperature control was performed through the use of a hot water bath, there was some lag time in the controller response to temperature change, resulting in the brief dips below 100 °F. This was also the cause of overshoots as the controller attempted to correct for these temperature changes. As previously shown in Table 2, outside ambient air temperatures experienced during testing ranged from approximately 90 °F, and down to an unseasonably cool 46 °F. This was due to a cold weather front that moved through the local area during testing. Every attempt was made to mitigate these fluctuations, but some dips outside of desired ranges were unavoidable. Despite this, the majority of operation was maintained at or above the 100 °F level.

The impact of the cooling effect of ambient air and wind from the cold front can also be seen in the intake air temperature of the engine. There was extensive deviation from the desired temperature of 100 °F, and the 24 -hour cyclical effect of day time heating and night time cooling is shown in Figure 10. Many adjustments were made to the test rig enclosure to offset these changes. Although not 100% successful, intake air temperature was maintained as high as possible, and it did not see as large of a temperature swing as observed in the ambient temperature outside the surrounding test area.

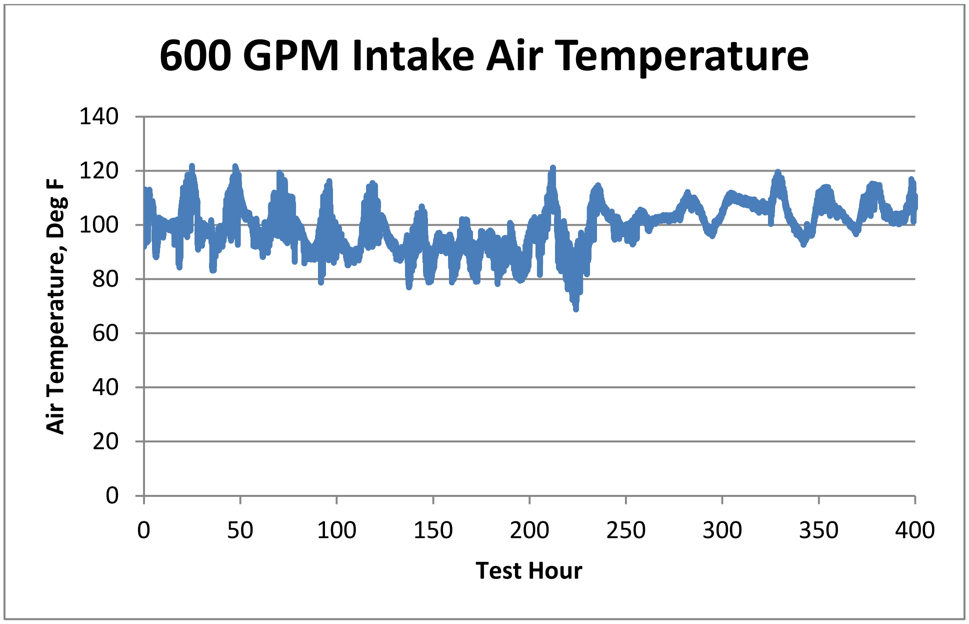


Figure 10. 600 GPM Intake Air Temperature

The overall water flow rate of the FPT pump-engine system is shown in Figure 11. The flow rate gradually changed over the course of the test as the pump output restriction was adjusted and as water temperatures stabilized in the entire system. As the rig was brought down for oil level checks, the position of the back pressure valve was manually adjusted to a slightly different position when brought back up to rated conditions. This was purely a function of operator variability. Like the pump speed, the spikes visible at various points are due to the shutdown process for oil level checks.

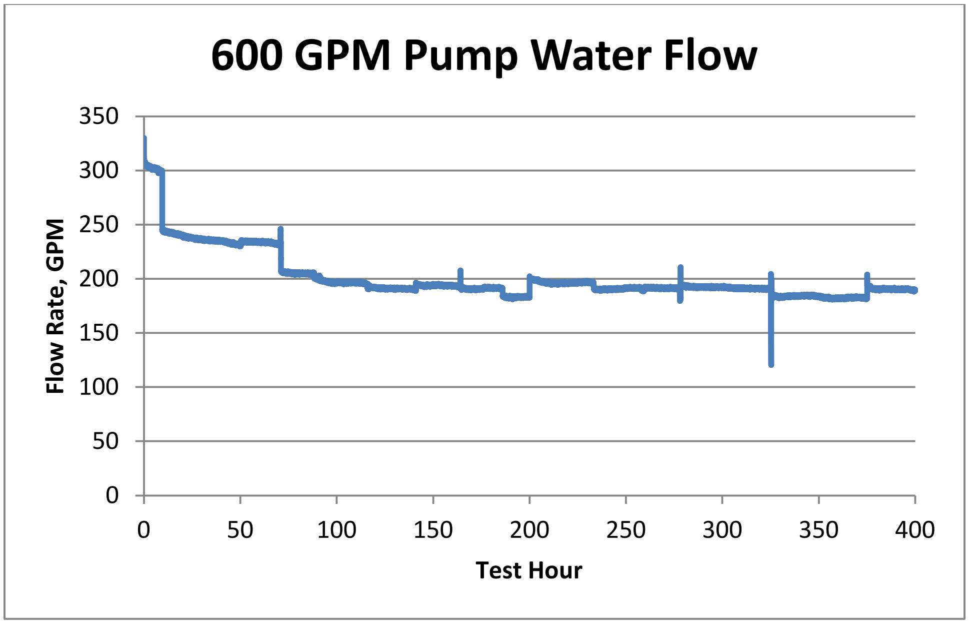


Figure 11. 600 GPM Pump Water Flow

While a high flow rate was most desirable, the initial 300 GPM rate was found to not be sustainable due to instability in conditions at the pump inlet. As previously mentioned, a single 4″ line was used for suction due to the limited fittings available on the water bladder. This is less than the 600 GPM Technical Manual recommendation of a single 6″ hose, or two 4″ hoses for suction side supply, thus resulting in suction side limitations (evident by engine speed fluctuations as suction side pressure went too low). After adjustment, a flow rate below 250 GPM was found to result in a suction side pressure of above 10 psiA, and provided stable engine operation. The remainder of the test was operated at that condition The resulting suction side pressure is shown in Figure 12. It should be noted that this value is reported in absolute pressure units.

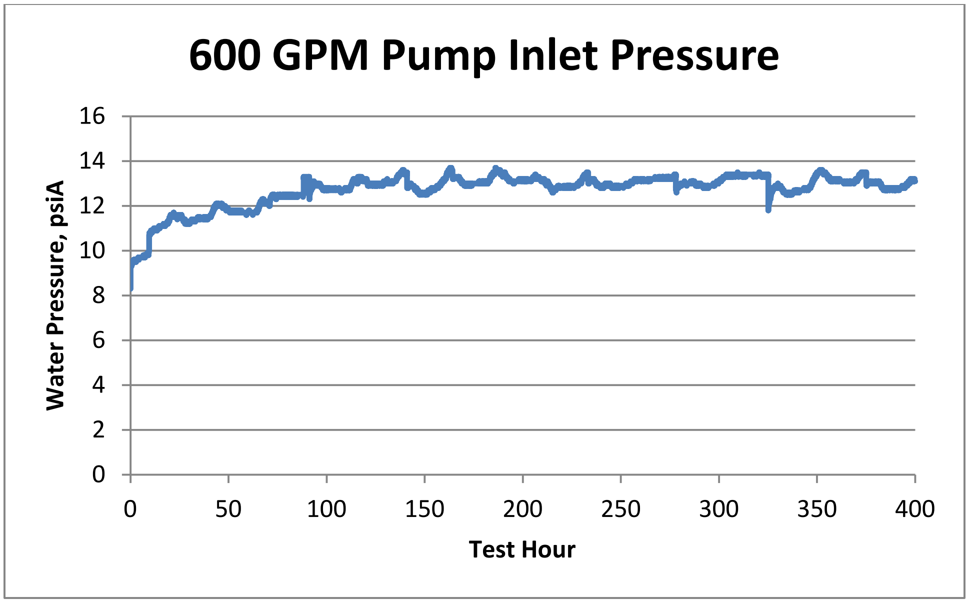


Figure 12. 600 GPM Pump Inlet Pressure

Water pressure at the outlet of the pump was less dependent upon fluid flow rate. This is shown in Figure 13. This pressure was measured prior to the backpressure valves on the discharge manifold. Despite the inlet pressure variation with flow changes through the system, the outlet pressure produced by the pump remained largely stable.

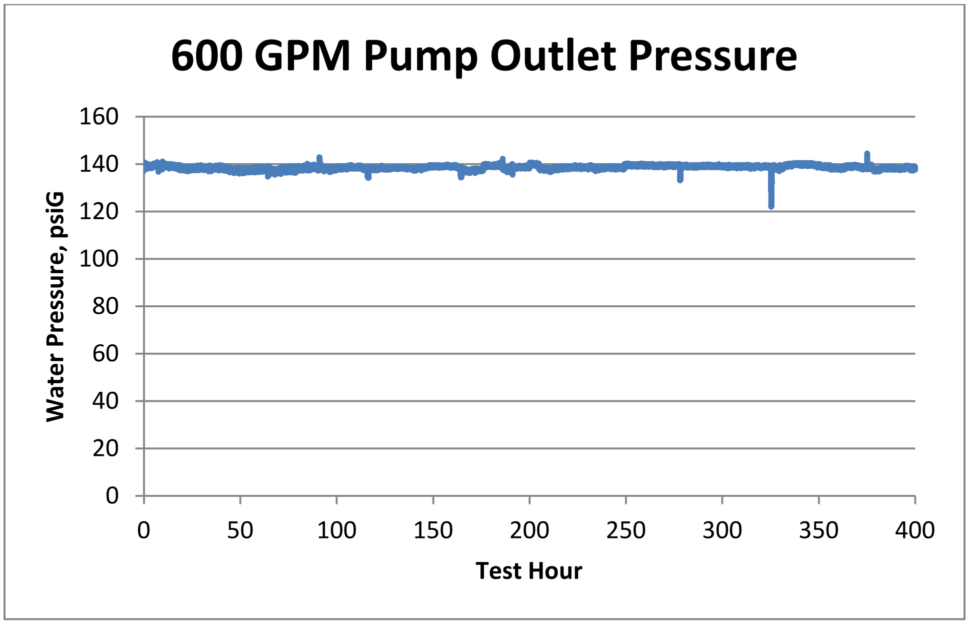


Figure 13. 600 GPM Pump Outlet Pressure

To control the overall flow rate, a valve between the discharge manifold and hose was used. Restricting the flow in this location provided control of the pump convenient to the operator, and reduced the line pressure in the flexible discharge hoses returning to the recirculation reservoir. Pressure at the hose inlet is shown in Figure 14

.

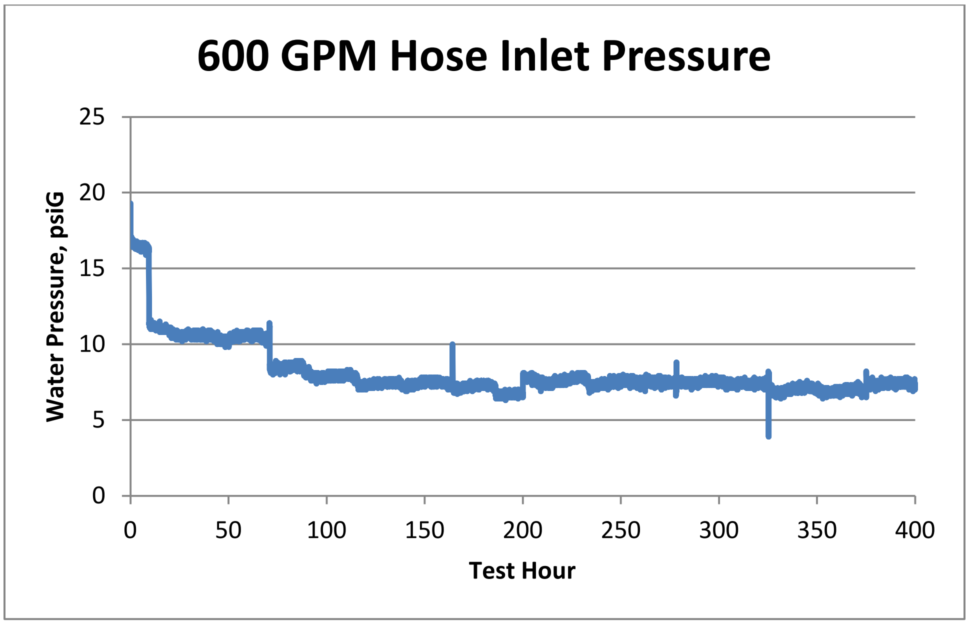


Figure 14. 600 GPM Hose Inlet Pressure

Similar to the flow rate and speed plots, the spikes seen in the data plot are related to the daily oil level checks of the rig and not an operational issue with the pumping unit.

Aside from the temperature control issues noted above, the pump-engine itself maintained stable performance throughout the test evaluation, and did not show any resulting issues from the use of the FT-SPK/JP-8 fuel blend. There were no changes noted in engine performance, or fuel system compatibility (i.e., fuel injection pump, injectors, fuel lines, etc) during testing. All observations indicated no compatibility issues were present with the use of the alternative fuel blend.

3.3 350 GPM PUMP ASSEMBLY

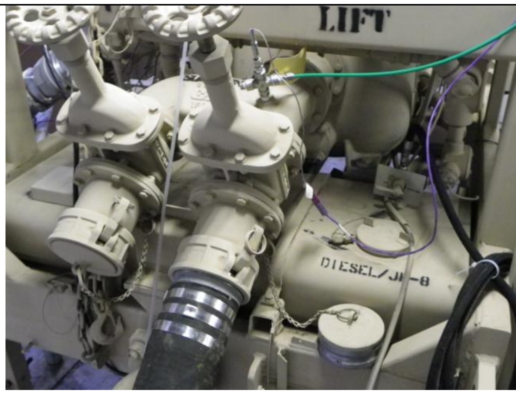
The following section discussion and results relate to the testing of the 350 GPM pump-engine assembly.

3.3.1 Installation and Set Up

After completion of testing on the 600 GPM pump-engine, it was replaced with the 350 GPM pump-engine in the existing test loop configuration. Similar instrumentation was installed to monitor pump inlet pressure, pump discharge pressure, water flow rate, and various temperatures to monitor testing. Specific locations for the key measurement parameters are shown in Figure 15.

In addition, an initial attempt was made to monitor engine speed to be consistent with the 600 GPM testing. This was attempted by using the pulsed output from the engine alternator during operation. However, it was found that once the batteries were fully recharged after start-up, the signal from the alternator became erratic and unusable for data acquisition. Other options were considered, but it was ultimately decided to run without monitoring the actual engine speed, as sufficient safeties were able to be programmed in from other measured parameters, and speed measurement would have required physical modification to the 350 GPM pump-engine assembly.

Consistent with testing completed on the 600 GPM pump-engine, both the fuel-water separator and final fuel filters were replaced prior to testing, and the system was flushed with the FT-SPK/JP-8 test fuel. The pump-engine oil filter was also replaced, and the system was charged with MIL-PRF-2104H SAE 15W-40. The MIL-PRF-2104H engine oil was also flushed into the intermediate shaft bearing as per startup instructions indicated on the 350 GPM pump-engine. Once complete, the pump was primed with water and operated to conduct a brief shake-down prior to testing.

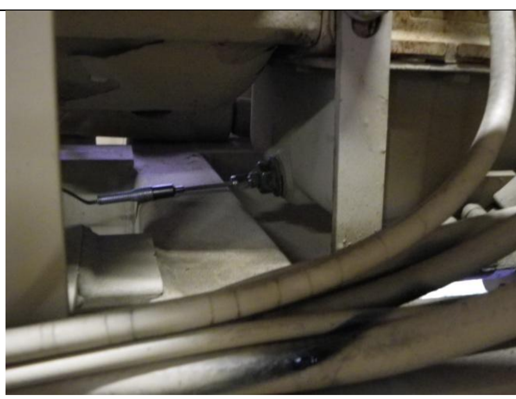


Pump Inlet Temp/Pressure

Pump Discharge Temp/Pressure

Hose Inlet Temp/Pressure

Intake Air Temperature



Oil Sump Temperature

Water Flow Rate

Figure 15. 350 GPM Instrumentation Locations

During this initial shakedown, it was found that the original 350 GPM unit sent from TARDEC for testing had some internal issues which prevented pump operation for any duration of time. After starting the engine, the engine immediately behaved as if it were under load. Any additional load applied to the pump would then have a dramatic impact on the overall engine speed of the assembly. Eventually this phenomenon would completely stall the engine, indicating that there may have been an issue with a bearing or other component inside the pump or engine creating excessive drag in the system. As a result, a second 350 GPM pump-engine was located by TARDEC staff, and sent to TFLRF for testing from Ft. Campbell, KY. This pump-engine was determined to be fully functional upon arrival, and the same preparation steps were taken on the replacement system prior to test start-up. Once completed, proper operation was confirmed through a second shakedown attempt, which was immediately followed by test initiation.

3.3.2 350 GPM Test Results

As with the 600 GPM pump-engine test, the 350 GPM pump-engine was shut down once per day to check the oil level and make any additions necessary. Other than this daily check, the test ran the full 400 hours continuously. Table 3 provides a summary of critical operational parameters over the entire test duration.

Table 3. 350 GPM Operational Summary

Parameter	Average	Minimum	Maximum	Standard Deviation	Median Value
Water Flow, GPM	278	33	437	40	289
Pump Outlet Pressure, psi	122.3	50.9	129.2	5.4	123.6
Hose Inlet Pressure, psi	6.3	2.2	13.3	1.1	6.3
Pump Inlet Pressure, psiA	10.5	6.1	14.2	1.1	10.4
Fuel Temperature, ° F	94.9	76.7	106.7	4.7	95.3
Intake Air, °F	107.5	86.0	126.1	7.7	108.0
Water at Pump Inlet, °F	110.1	62.5	125.2	13.9	115.3
Water at Pump Discharge, °F	110.7	63.1	126.2	13.9	115.9
Water at Hose Inlet, °F	110.8	63.6	126.0	13.9	116.1
Engine Oil Sump, °F	219.2	181.6	225.8	2.9	219.7
Air Outside Test Area, °F	63.1	44.4	85.5	7.7	63.2

Like the 600 GPM test, the fuel inlet temperature was desired to be at 100 °F minimum. This temperature response over the test duration is shown in Figure 16.

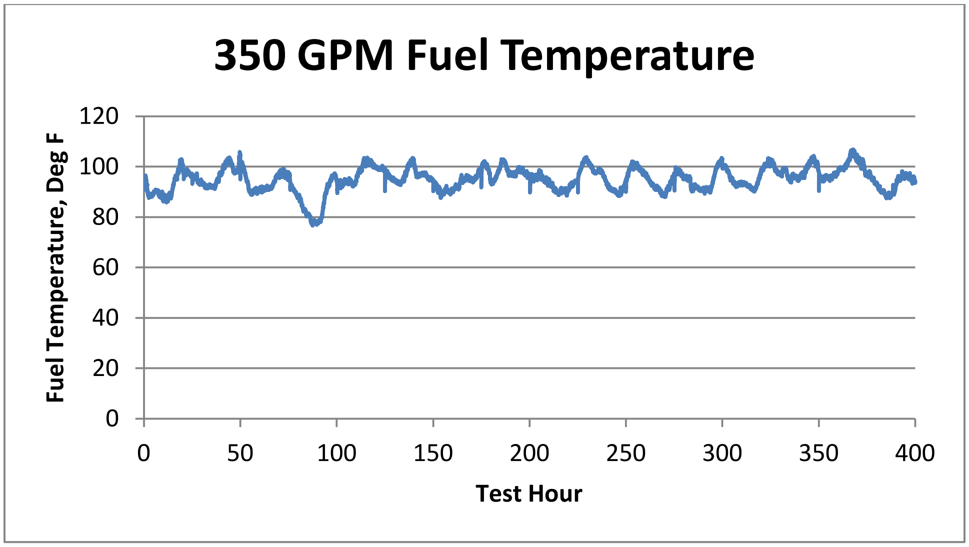


Figure 16. 350 GPM Fuel Temperature

Like the 600 GPM test, inlet fuel temperature again followed ambient air conditions which saw similar extremes, and the average temperature over the 400 hr test fell short of the 100 °F target, resulting in an average value of 94.9 °F. The low return fuel flow volume of this particular engine impacted the heat build-up in the small day tank the rig was running off of, which combined with ambient air temperature variation, ultimately prevented the desired control over fuel inlet temperature, despite the water bath heating.

Intake air temperature was measured at the inlet to the air filter on the engine, and is shown in Figure 17. The insulation around the pumping rig was able to keep the air temperature elevated above 100 °F throughout the majority of testing. Air drawn past the radiator by the cooling fan resulted in a high recirculation rate within the enclosure. This prevented gusts of wind from the outside area from having as large an impact on intake temperature as seen in the 600 GPM testing.

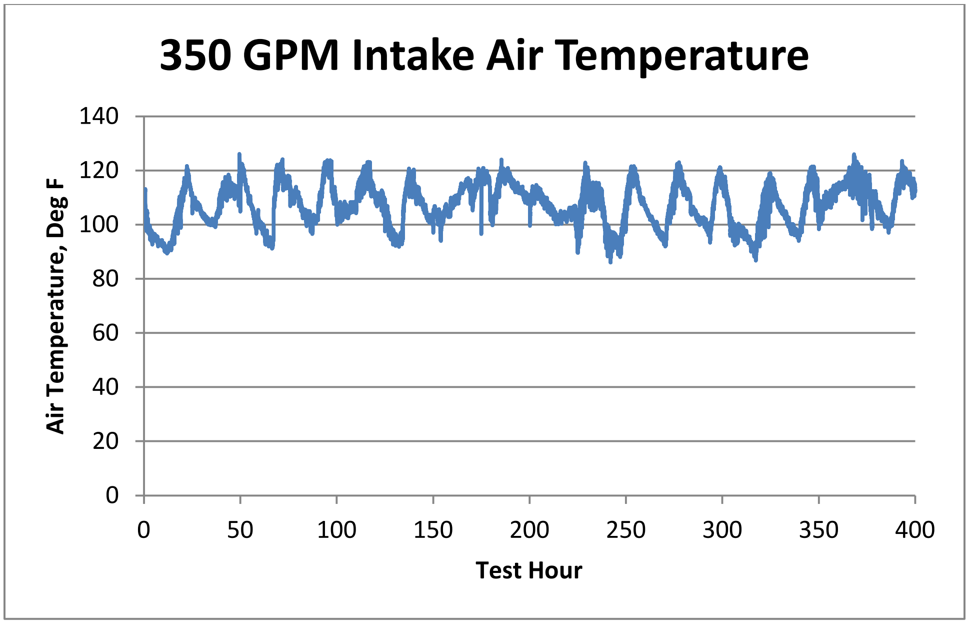


Figure 17. 350 GPM Intake Air Temperature

The flow rate of water through the system is shown in Figure 18. Unlike the 600 GPM testing, the 350 GPM pump-engine was designed for operation using a single 4″ supply hose, and as a result was able to flow closer to its specified nameplate volume. The changes in flow seen throughout testing were again due to the rig being stopped daily for oil level checks, and resulting backpressure valves reset to a different location upon resumption of testing. The rapid increase in overall water flow seen after the first two daily checks was a result of a calculated function of pumping power being added to the test program. This provided operator feedback when starting the system so that valves could be adjusted to produce the highest possible pumping load on the engine, ultimately providing more consistent setting of the equipment at the desired operational conditions.

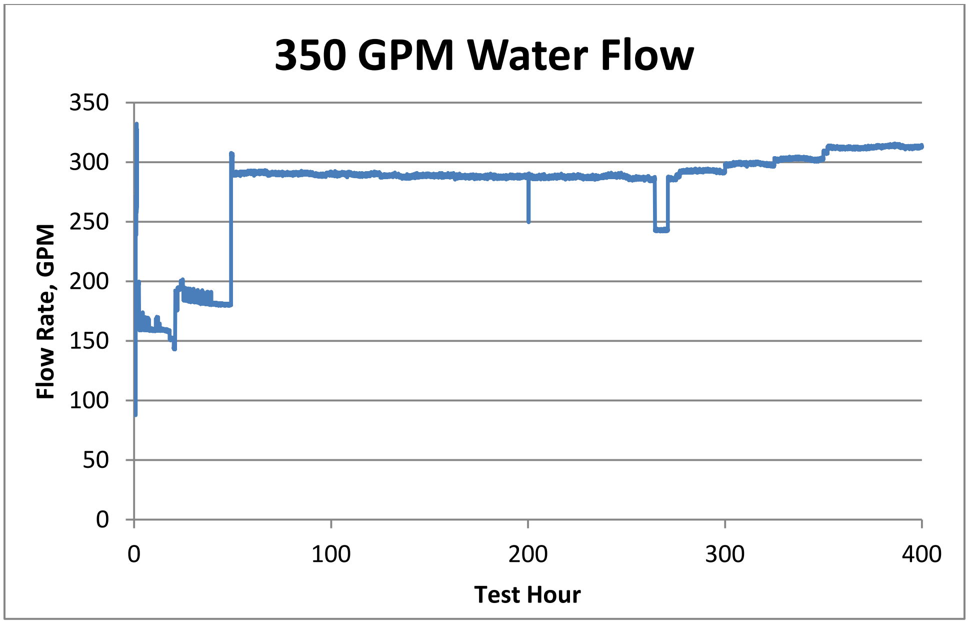


Figure 18. 350 GPM Pump Water Flow

The suction side pressure is shown in Figure 19. The adjustment of flow rate and discharge restriction can also be seen in this recorded data. As the overall flow of the system increased, a larger suction was placed on the supply hose resulting in a lower inlet pressure.

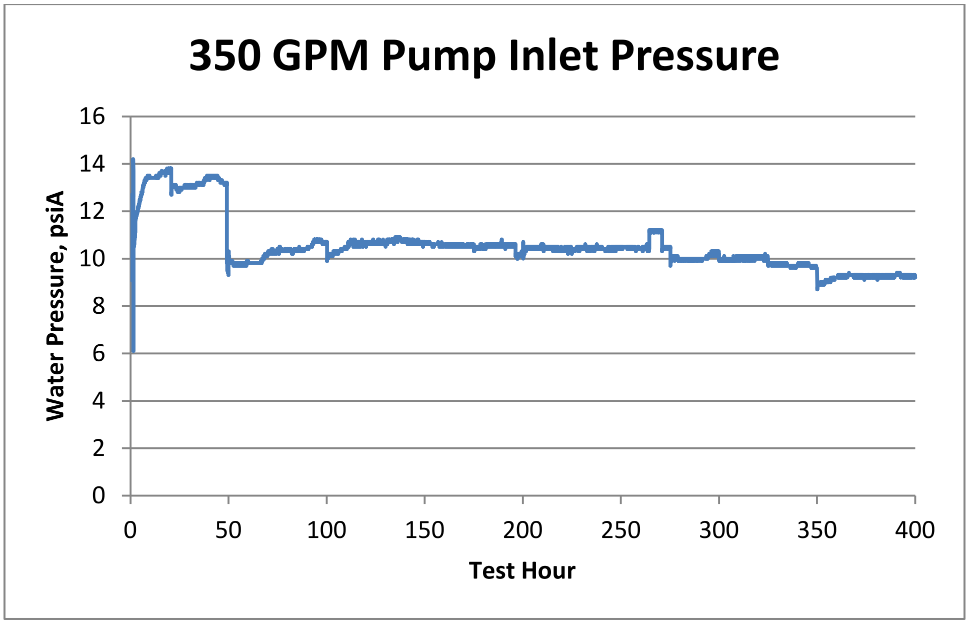


Figure 19. 350 GPM Pump Inlet Pressure

As expected, water pressure at the outlet of the pump was impacted by fluid flow rate and is shown in Figure 20. During the first 50 hours of testing, the outlet pressure of the pump (measured prior to the restriction valve) increased from around 100 psi to 125 psi. The flow rate over this same period increased from around 100 GPM to 180 GPM, and then finally up to 290 GPM. One interesting item to note is that the discharge pressure experienced a larger increase when the flow changed from 100 to 180 GPM than that seen by the final 100 GPM increase in flow rate. This appears to be related to pump speed rather than any impact the fuel had on operation of the rig.

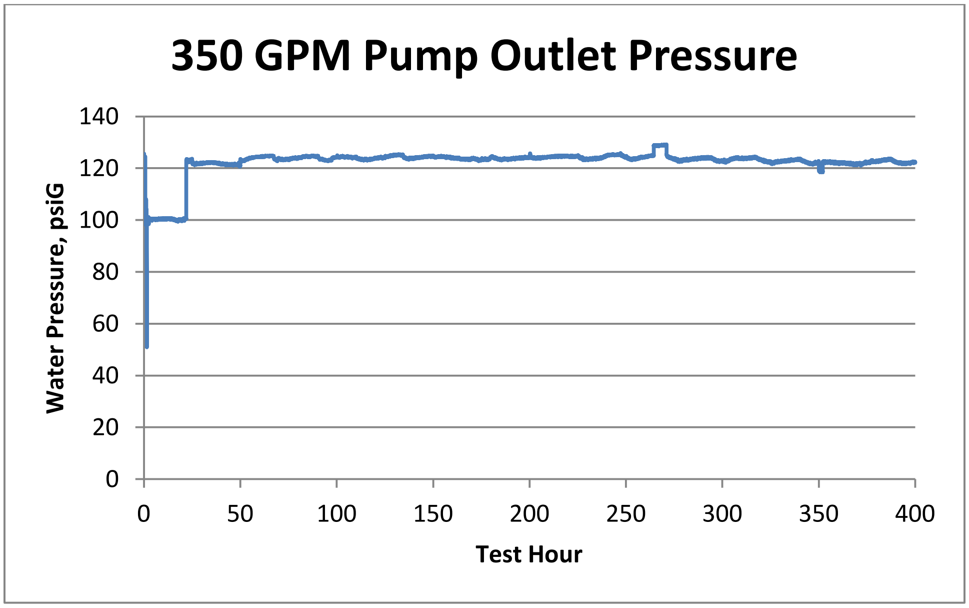


Figure 20. 350 GPM Pump Outlet Pressure

Pressure at the hose inlet is shown in Figure 21. The hose inlet pressure was measured immediately downstream of the restriction valve for the flow loop. As the valve setting was changed after shut-downs, the pressure within the hose trended directionally with the water flow rate.

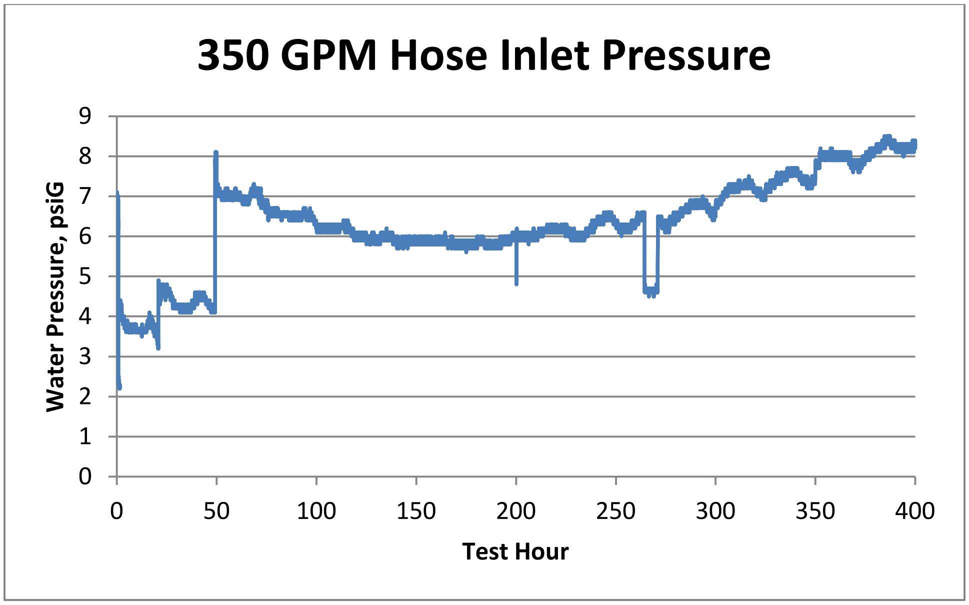


Figure 21. 350 GPM Hose Inlet Pressure

As with the 600 GPM pump-engine testing, no operational issues in the 350 GPM pump-engine were observed as a result of the use of the FT-SPK/JP-8 blend. The engine maintained a satisfactory level of performance over the 400 hr test duration, and no compatibility issues were noted with the pump-engine fuel system (i.e. fuel injection pump, injectors, fuel lines, filters, etc), or output performance. All observations indicated no compatibility issues were present with the use of the alternative fuel blend.

4.0 ADVANCED AVIATION FORWARD AREA REFULEING SYSTEM TESTING

This section covers the evaluation of the Advanced Aviation Forwards Area Refueling System (AAFARS) using the FT-SPK/JP-8 blend. The AAFARS system is a modular petroleum handing and distribution system consisting of an engine powered pumping module, 500 gallon collapsible fuel storage tanks, various fuel distribution nozzles, and dry brake uni-sex hoses and fittings for a flexible/modular configuration.

4.1 TEST FACILITY

Unlike the FPT pump-engines, the AAFARS was evaluated not only using the FT-SPK/JP-8 blend in the engine pumping module, but also in the remaining components of the AAFARS fuel distribution and handling system, to assess material compatibility with all of the various components. As a result, additional preparations were made to ensure safe and proper handling of the fuel being used to operate the system and recirculate in the flow loop.

The use of the fuel blend in all components of the system dictated that testing had to be conducted in a liquid containment area, so that any fuel leaks would be controlled in the event of a system malfunction or general spill. To achieve this, a portable/collapsible 5,000 gallon containment berm was purchased for testing, and all components of the AAFARS system were setup within the contained area. In addition, the entire AFFARS test setup and portable containment berm were located within a larger existing earthen berm containment area at TFLRF for an added level of protection.

Multiple safeties were included in the AAFARS installation to help prevent spills, or minimize them in the event of a component failure. This included:

- Monitoring of pressures before and after every AAFARS component to sense any unusual pressure drops or changes (in absolute and delta pressure), which would indicate a leak or malfunction
- Pressure safety switches installed in key locations in the recirculation loop
- Installation of the supply tank and the AAFARS pumping module within smaller steel containments for additional spill capacity
- Mechanical locking of all cam-lock fuel fittings to prevent accidental separation due to vibration

In addition to the steps taken for fuel spills, the entire system was bonded and grounded to prevent any potential charge build up in the system, and the test fuel was additized as required with a static dissipater from the JP-8 approved products list. All mechanical grounding connections were verified for continuity by a certified electrician prior to testing as a final check, and the electrical conductivity of the fuel blend was routinely monitored throughout testing to ensure acceptable conductivity levels to prevent static buildup. All of these steps provided the safest test possible when using the fuel blend itself in the experimental setup.

4.2 INSTALLATION AND SET UP

The same basic data acquisition and control system used in the FPT pump-engine testing was reused for the AAFARS system evaluation. Direction was given by TARDEC to install as many of the AAFARS components in the test loop as feasibly possible. In the end, all components of the AAFARS system provided by TARDEC were represented in the system, with the exception of the CCR and Fuel/Oil servicing nozzles. These nozzles were not included due to limited means to incorporate them into the sealed system recirculation loop in a safe manner. As a result, only the D1 nozzle with appropriate adapters to the uni-sex and cam-lock components of the system was incorporated.

The original system layout developed and approved by TARDEC consisted of a single large recirculation loop tied to a 3,000 gallon collapsible bladder provided by an outside supplier. It was connected in such a manner that the pump module pulled its fuel supply from the 3,000 gallon bladder, and the pump then discharged through the flow meter, D1 nozzle, and the 500 gallon collapsible fuel drum, returning fuel back to the bladder in a serial manner. Instrumentation was setup to monitor the pump and fuel drum pressures, fuel flow, and various temperatures throughout the system. Initial shakedown was completed to test the overall flow arrangement, and two problems became readily apparent. The first issue noted was the inability to recirculate the fuel back to the 3,000 gallon bladder. The bladders original configuration was provided by the outside supplier in a one port configuration. This limited the ability to connect the required supply and return hoses to the system, so an adapter was made to return fuel at the same location as the bladder air vent. Ultimately it was found that the air vent could not be prevented from releasing fuel while the system was being operated, thus the bladder would have to be replaced. Secondly it was apparent that the 500 gallon AAFARS fuel drum was experiencing fuel supply pressures from the pumping module nearing its rated test pressure as per its design parameters called out in MIL-D-23119G. For safety reasons, the system was then shut down to determine possible solutions to these noted issues.

Several adjustments and test attempts were made, with the final solution consisting of the replacement of the 3,000 gallon bladder with a smaller 500 gallon rigid fuel storage tank, and the split of the single path flow loop into two flow paths using the AAFARS 4-port recirculation manifold. This allowed the modification of the 500 gallon rigid recirculation tank to achieve the proper supply, return, and vent fittings to allow proper recirculation. In addition this provided limitation in pressures being subjected to the AAFARS 500 gallon collapsible tank without restricting volume flow through the remaining hoses and D1 nozzle loop. Figure 22 and Figure 23 show the final test operating configuration, and a diagram of the flow loop with indication of locations for the measured parameters.

Figure 22. AAFARS final test set-up

In effect, the pumping module pulled fuel from the 500 gallon rigid tank and discharged into the 3 inch port on the recirculation manifold. From the recirculation manifold, the 2 inch open port then connected to the flow meter through the D1 nozzle and returned to the storage tank, while the 2 inch orifice port of the recirculation manifold was connected to the 500 gallon collapsible fuel drum, which then returned to the storage tank. This configuration provided the 500 gallon collapsible fuel drum with pressures less than 5 psi, but still maintained some nominal flow through the components. The pump module engine itself was supplied fuel by a float level controlled “day tank” to prevent operators from having to manually fill the onboard fuel tank over the test duration. The “day tank” used was provided fuel at regulated pressures from the discharge of the pump module in the recirculation loop, essentially creating a self contained system.

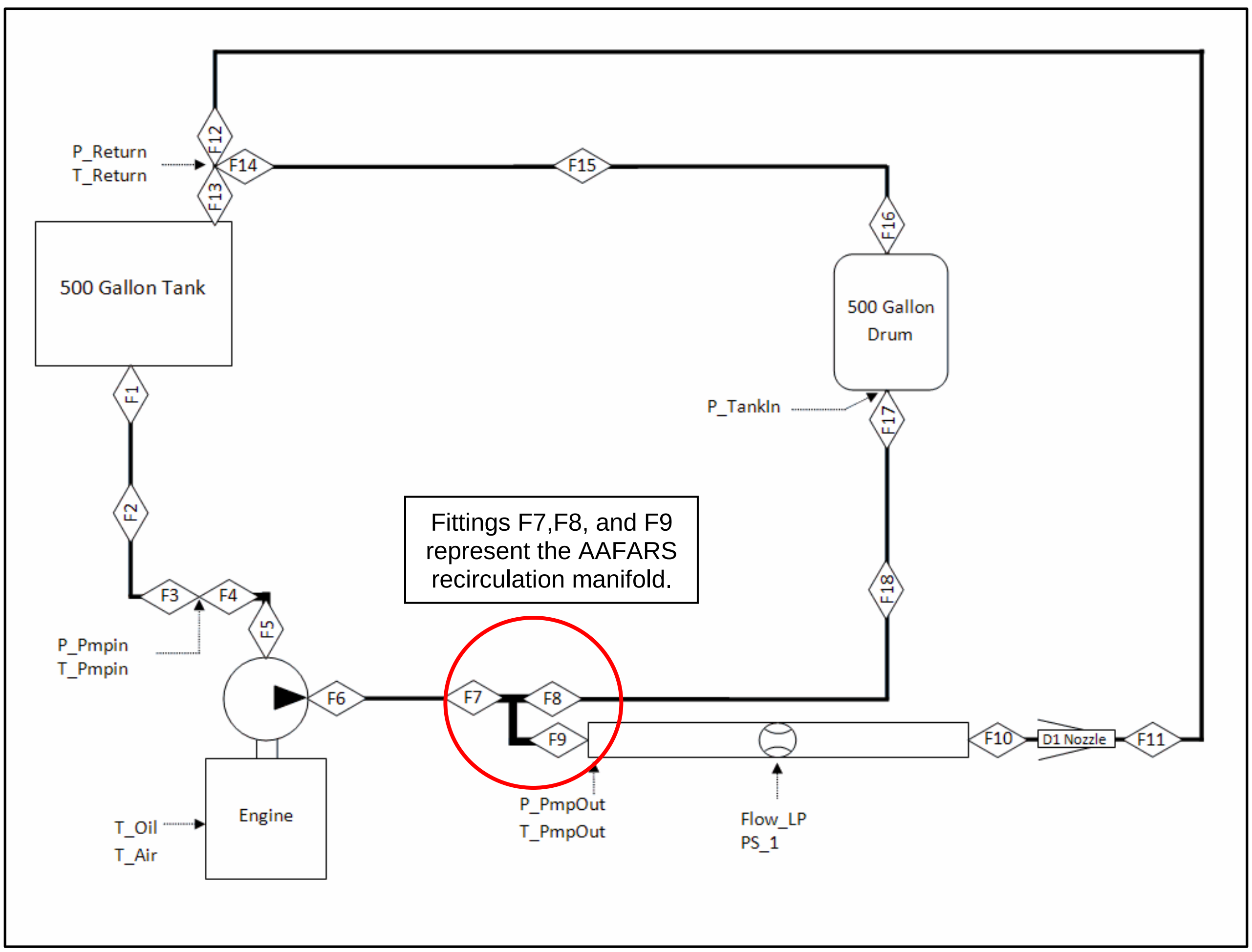


Figure 23. AAFARS test configuration diagram

After successfully completing shake down with the new system layout, operating limits were set within the PRISM data acquisition and control system to ensure safe operation of the system for the 400 hr test.

4.3 AAFARS Test Results

Consistent with the FPT pump-engine testing, a daily shutdown was performed to check engine oil level and top off as needed. Apart from this, the system ran non-stop for the 400 hr test duration with the exception of a few system malfunctions. These malfunctions included:

- A shutdown at 98 hours as a result of a failed pump drive coupling. Failure was attributed to the high temperature environment, and a new coupler was installed and testing resumed.
- Fuel leaks were noted at approximately 3-4 unisex couplers on multiple occasions during system shutdowns at daily oil level checks. Most were easily repaired with replacement uni-sex seals, with removed seals being found with some sort of mechanical damage (pinch or roll in the body). Couplings, F1 and F2 shown in Figure 23 were found to have pitting from corrosion around the seal in the seal seating groove. Even after the seals were replaced at these locations, minor leaking reoccurred during system shutdowns daily. No leaks were attributed to the fuel being tested itself, as all appeared to be a result of the age of the seals and corrosion of the couplers. Since no leaks were present during system operation, testing was continued.
- A shutdown at 205 hours as a result of a fuel leak that occurred on the engine fuel supply hose between the injector pumps. The hose was found to have multiple cracks on the OUTER layer of the hose. The failure was attributed to exposure to heat from the engine compartment, and not a result of interaction with the test fuel. A replacement section of bulk hose was installed and testing was resumed.

Table 4 shows the operational parameters for the 400 hr test. Like the FPT testing, the desired fuel temperature was specified at a minimum of 90 °F. Fuel temperatures in the system were measured at the suction side of the pump, and again at approximately 4 feet after the discharge at the inlet to the flow meter (See T_PmpIn and T_PmpOut in Figure 23). Unlike the FPT testing, the AAFARS tests were completed during the summer months, which resulted in no issues in achieving the desired fuel temperatures.

Table 4. AAFARS Operating Condition Summary

Parameter	Average	Minimum	Maximum	Standard Deviation	Median Value
Fuel Flow Out of Pump, gpm	86.7	74.8	92.8	3.6	88.1
Pressure at Pump Outlet, psig	6.2	5.1	8.2	0.4	6.2
Pressure at Pump Inlet, psia	10.1	8.8	11.3	0.3	10.1
Pressure at Fuel Drum, psig	0.9	-0.1	2.5	0.6	0.7
Fuel Temperature at Pump Outlet, deg F	116.9	90.3	137.3	9.3	115.4
Fuel Temperature at Pump Inlet, deg F	116.4	90	136.7	9.3	115

As expected, the bulk fuel temperature did fluctuate with ambient air temperature. The pump unit inlet fuel temperature is shown in Figure 24.

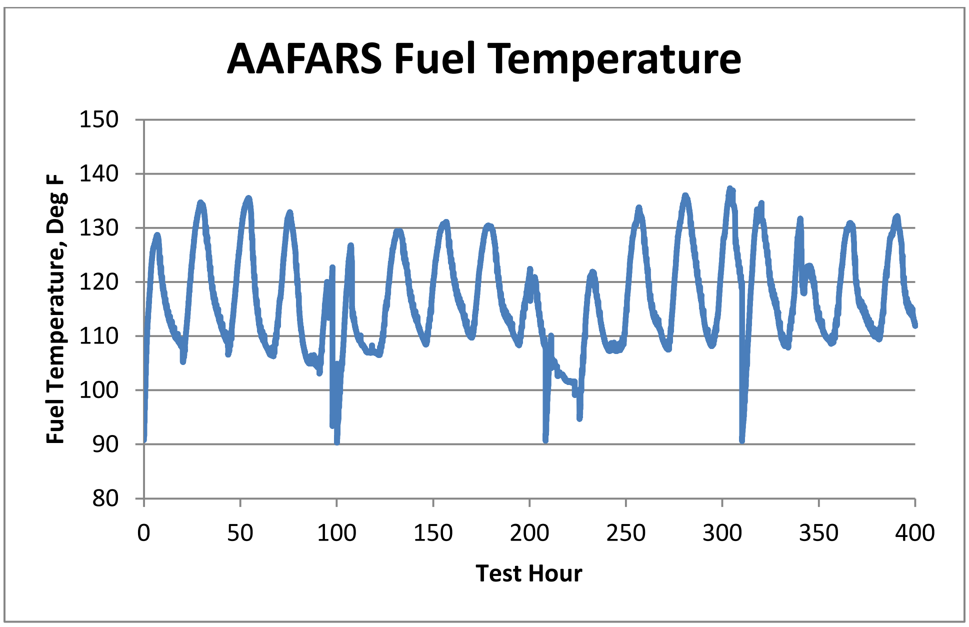


Figure 24. AAFARS system fuel inlet temperature

The ambient air temperature was also recorded near the engine and pump unit. A small frame with doors and covers was constructed around the AAFARS pump unit itself prior to testing to help control ambient air temperatures as much as possible. Air temperature immediately around the pump unit still varied with the time of day, but with the doors and covers around the pump engine, ambient air temperature was easily maintained between 91.5 and 137 °F throughout testing. When air temperature was lower, the doors were closed to maintain the engine temperature, and when temperatures were higher, they were reopened. The ambient air temperature is shown in Figure 25.

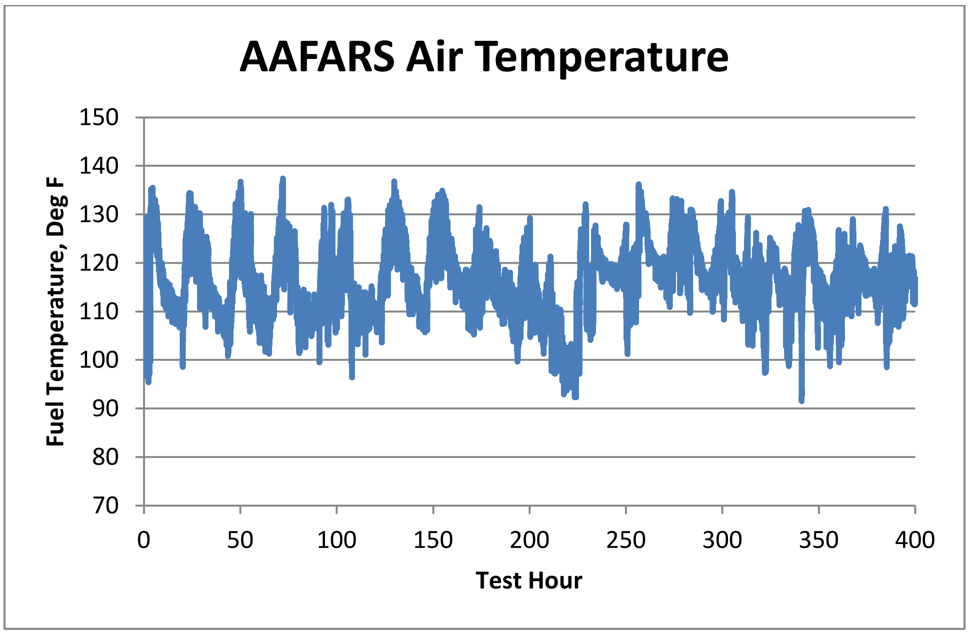


Figure 25. AAFARS system ambient air temperature

The overall fuel flow in the recirculation loop was measured just after the discharge of the pump and ahead of the D1 nozzle (see Flow_LP in Figure 23**)**. The fuel flow data shows a slight increase near 91 hours of operation. The exact cause of this is unknown, but has been identified to have occurred after a routine shutdown and restart early in the test. After this shift, the fuel flow remained consistent for the remainder of the test. The flow rate data for the system is shown in Figure 26.

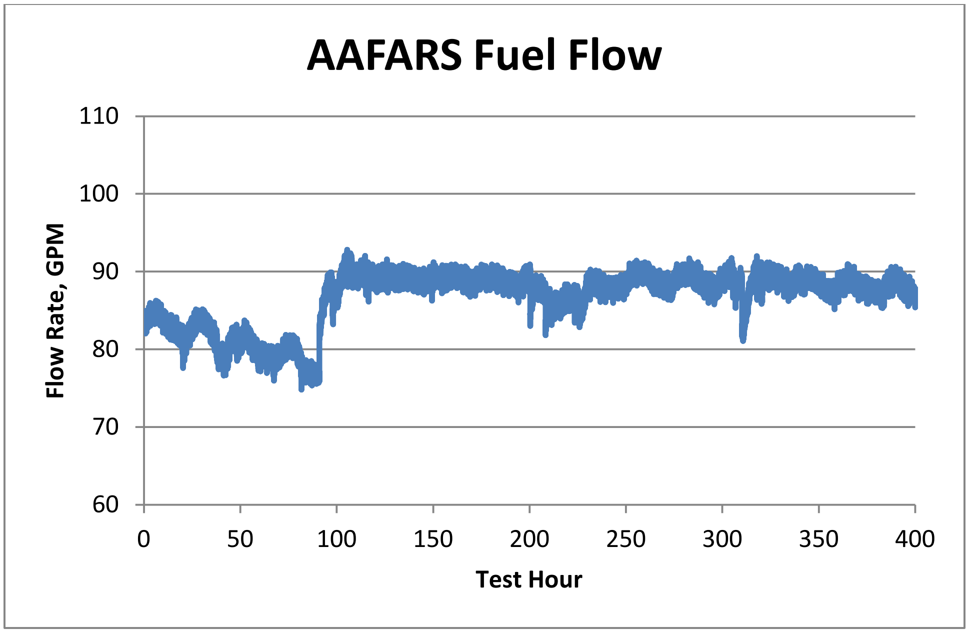


Figure 26. AAFARS system overall fuel flow rate

The fuel inlet and outlet pressures of the AAFARS pump was measured at the inlet suction side of the pump, and after the pump prior to the flow meter. The fuel pressure at the pump inlet shows a slight decrease near the 91 hours, while the outlet shows a slight increase. Both are a result of the increased system flow rate that was previously noted. In addition, daily fluctuation of pressure can be seen in the plot as a result of heating and cooling of the fuel in the recirculation loop which affected the fuels viscosity and resulting pressure generated by the pump. Inlet and outlet pressures are shown in Figure 27.

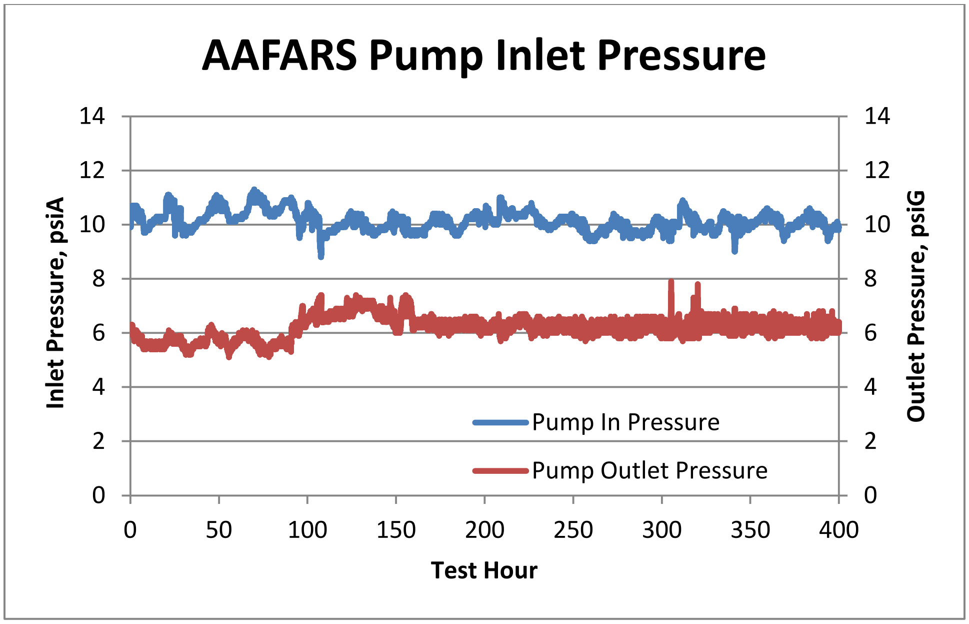


Figure 27. AAFARS system pump inlet and discharge pressure

The 500 gallon fuel drum pressure was measured at the drum inlet after the 2 inch orifice port from the recirculation manifold to ensure the drum was not exposed to excessive pressures that could rupture the tank. The fuel drum pressure remained below 2.5 psiG for the entire test ensuring safe operation. The fuel drum pressure is shown in Figure 28.

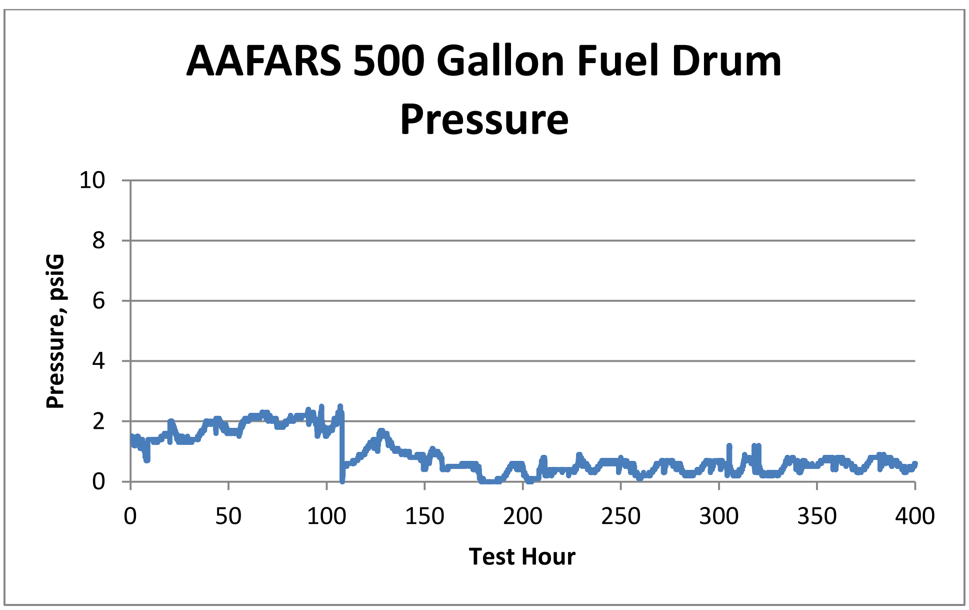


Figure 28. AAFARS 500 gallon fuel drum pressure

4.4 ENGINE DRIVEN PUMP ASSEMBLY TESTING SUMMARY

Similar to the FPT testing results, the 400 hr AAFARS test showed that the FT-SPK/JP-8 fuel blend had no direct impact on the operation of the equipment. While some minor leaks were noted at various fittings during testing, all were attributed to mechanically failed o-rings from previous seal deformation and corrosion/pitting in the fitting groove where the seal was seated. The remainder of the AAFARS system demonstrated satisfactory performance with the fuel blend, and would not be expected to demonstrate compatibility problems with future use.

5.0 CONCLUSION

Results from both the FPT and AAFARS testing yielded satisfactory performance when operated on the FT-SPK/JP-8 test fuel blend. Each system was able to be operated to their full capacity as dictated by the test facility and hardware used in the evaluation. No engine related performance issues were noted in either component as a result of operating the engine on the synthetic blend fuel, and no fuel related material compatibility issues were noted with hardware components that came into contact with the test fuel itself (i.e., fuel engine supply and return lines, AAFARS suction/discharge lines and fittings). Some performance issues were experienced in testing, but all were related to incorrectly assembled test hardware, or age/previous wear or damage of the equipment. It is expected that these two systems, assuming proper starting function, can be operated on FT-SPK blends by the Army in the future without experiencing any major compatibility problems or performance shortcomings.